Aalto University
School of Chemical
Engineering

From Siloed Operations to Co-Designed Energy Systems: Scheduling, Control and Flexibility

Nordic Process Control Workshop 2026

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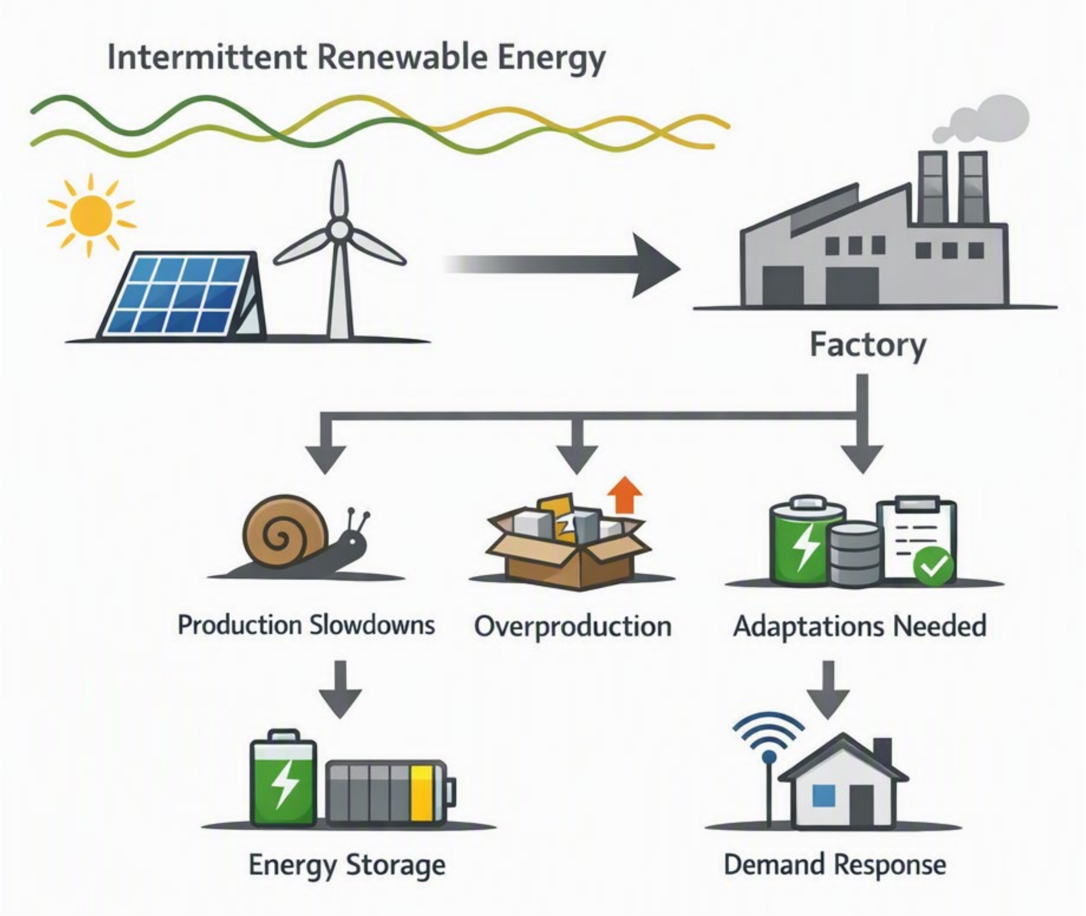
Motivation: Coupled Power–Process Systems

- Energy transition intensifies dependencies between power grids and industrial processes
- Non-dispatchable renewables increase variability and uncertainty
- Need reliable, cost-efficient, and resilient coordination across timescales



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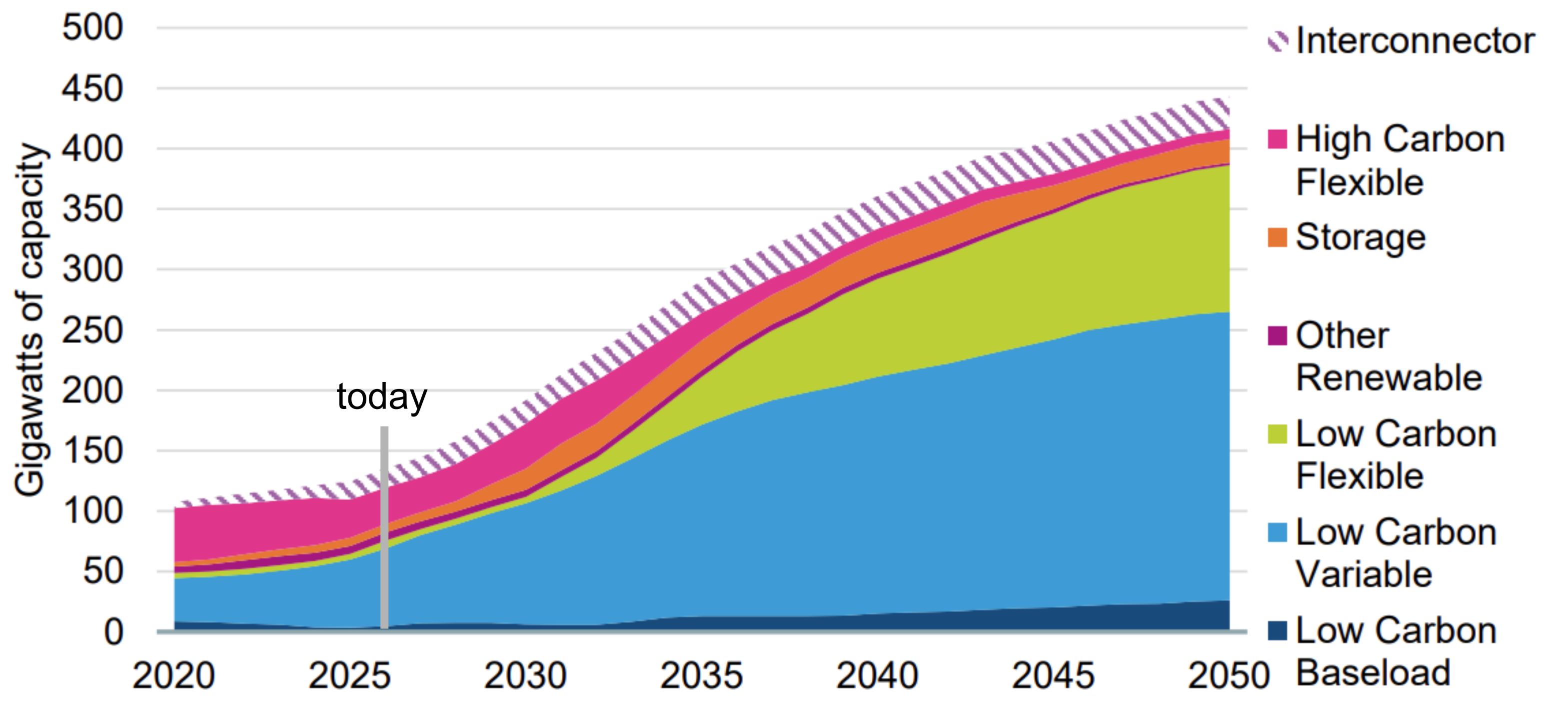
Strong Increase of Renewable and Variable Energy Sources (UK)

- Non-dispatchable supply keeps growing
- Balancing moves closer to real time
- Energy storage cannot carry every response
- Industrial loads add controllable demand (e.g. demand-response)

Figure 1: Illustrative Capacity Mix, 2020-2050, GW, BEIS Higher Demand Scenario



High Carbon Flexible: Peaking (incl. OCGT), CHP Gas, CCGT, Coal

Storage: Battery, Pumped Hydro, Other

Other Renewable: Hydro, Other RES

Low Carbon Flexible: Biomass, Gas CCUS, Hydrogen

Low Carbon Variable: Solar, Onshore Wind, Offshore Wind

Low Carbon Baseload: Nuclear, BECCS

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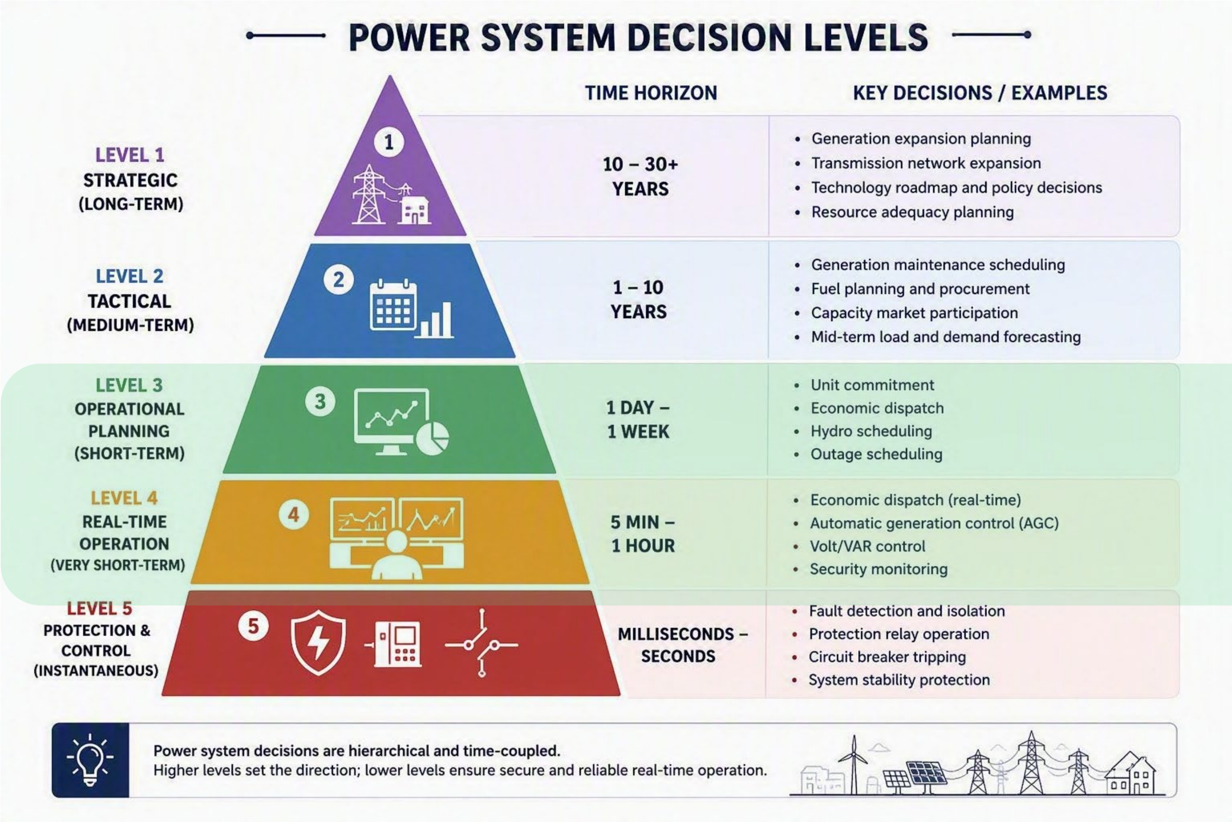
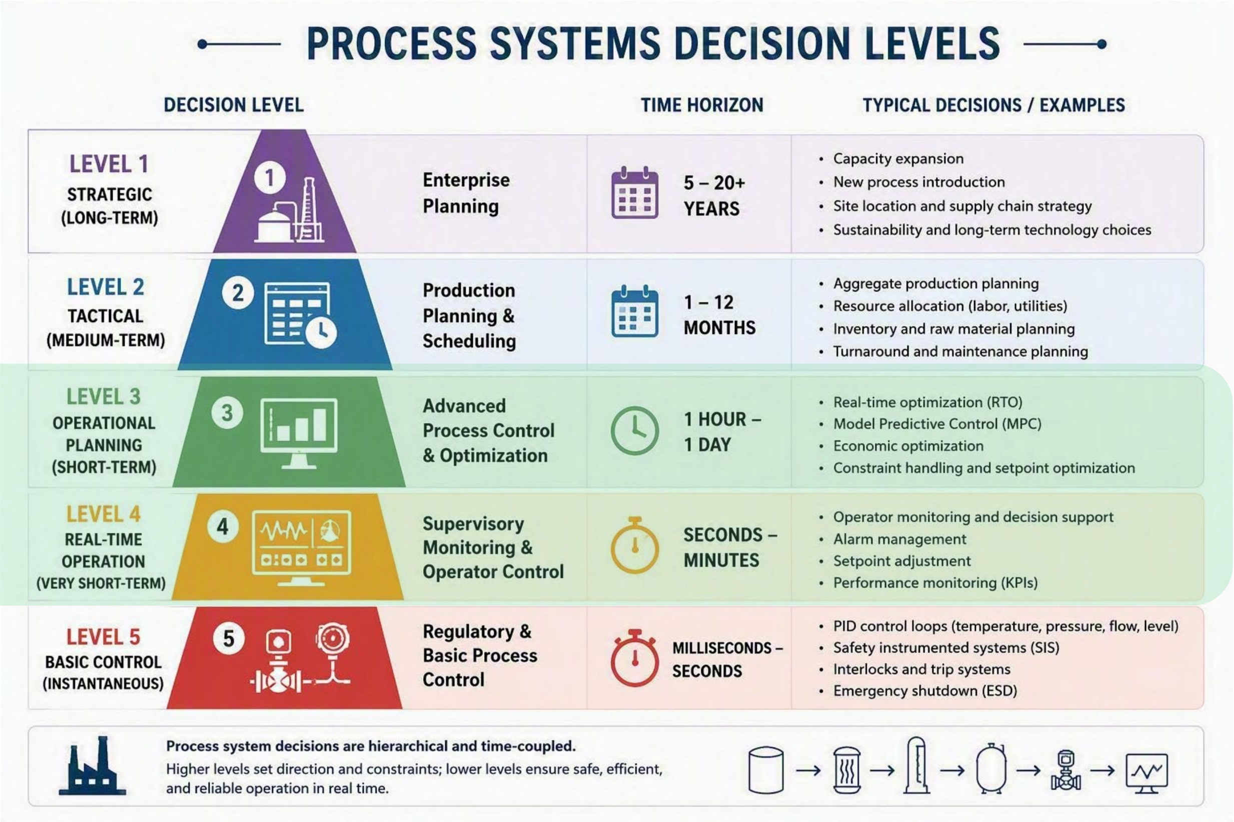
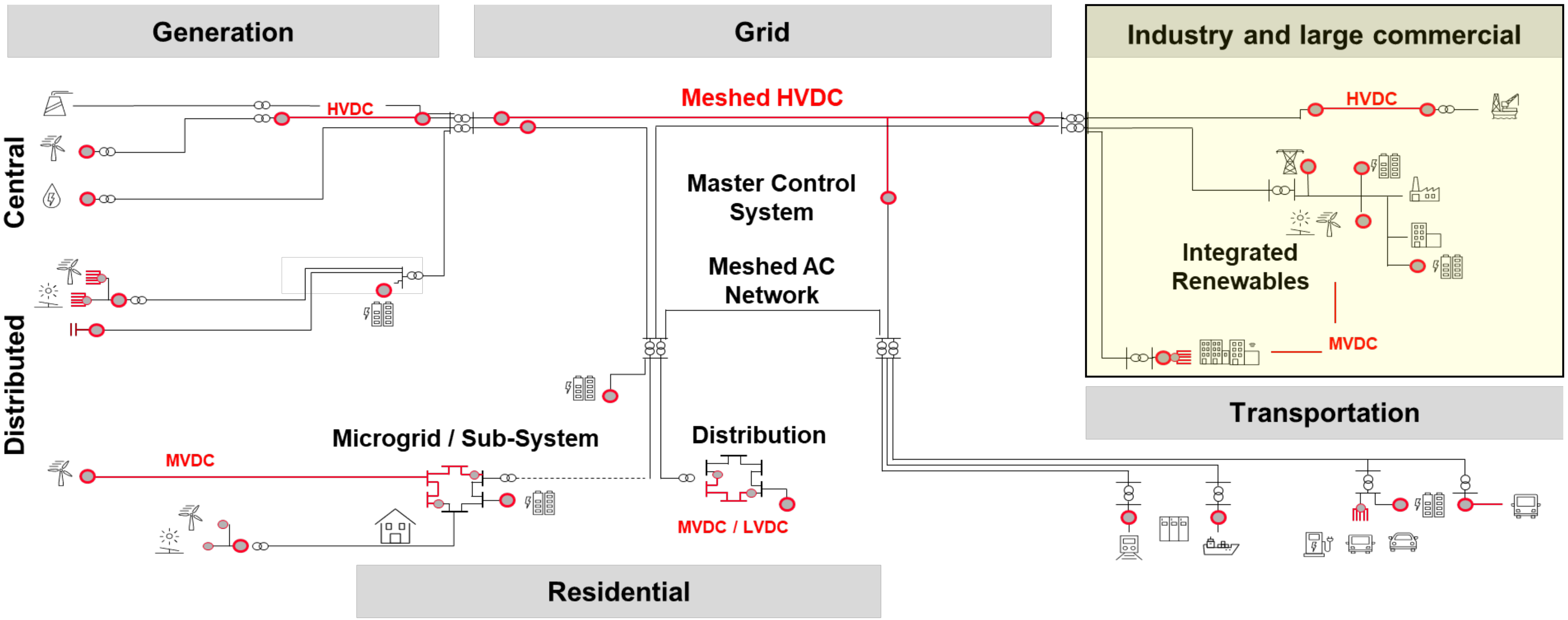
Both Systems Have their Own Strong Decision Hierarchy





The Future Power System of Systems



Sustainable, embedded AC & DC systems will require advanced power electronics and digital technologies

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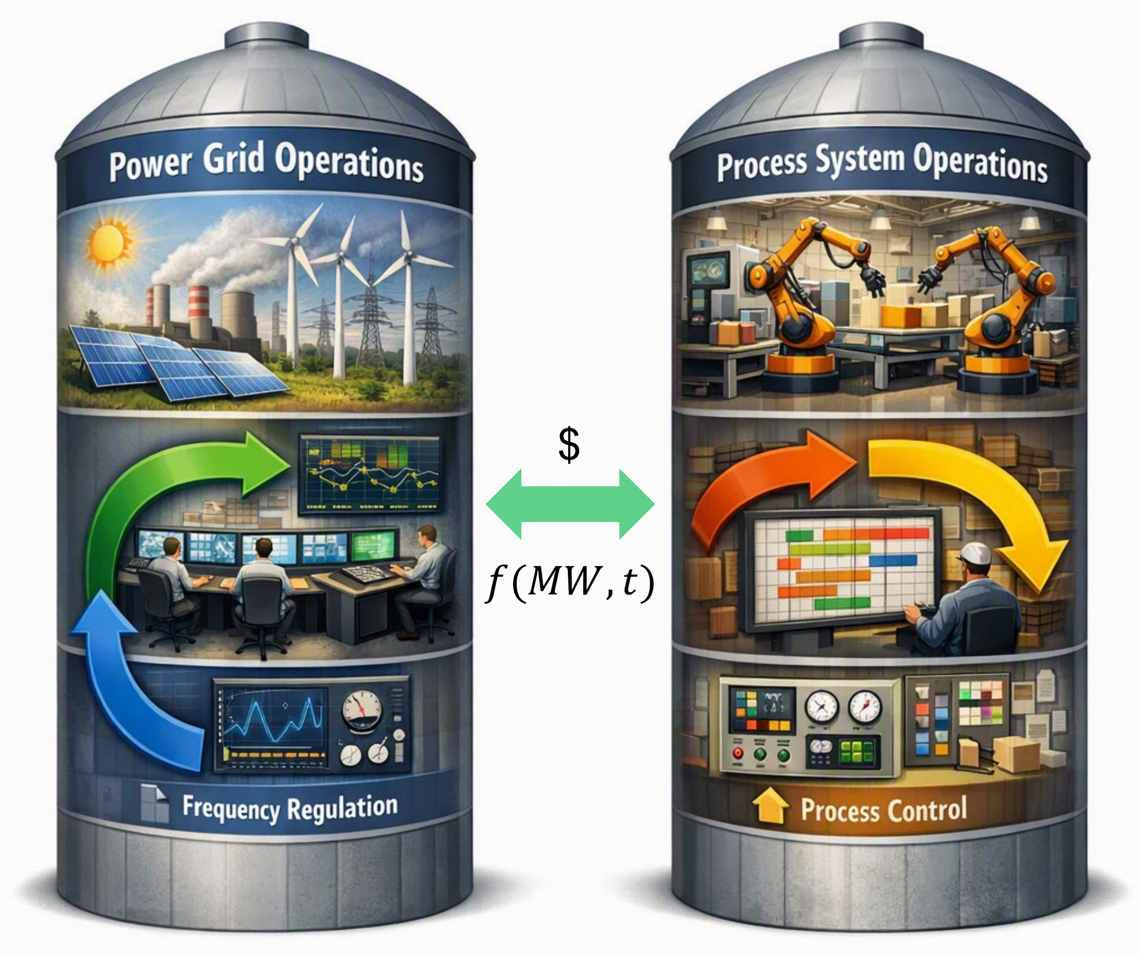
Source: Hitachi Energy

The Problem with Siloed Operations

- Separate optimization of grids and processes misses cross-domain flexibility
  - Results: suboptimal costs, lower reliability, missed value streams
- Integrated “scheduling-with-control” outperforms siloed approaches on cost, reliability, sustainability
  - Key questions:
    - What to plan together?
    - What to control together?



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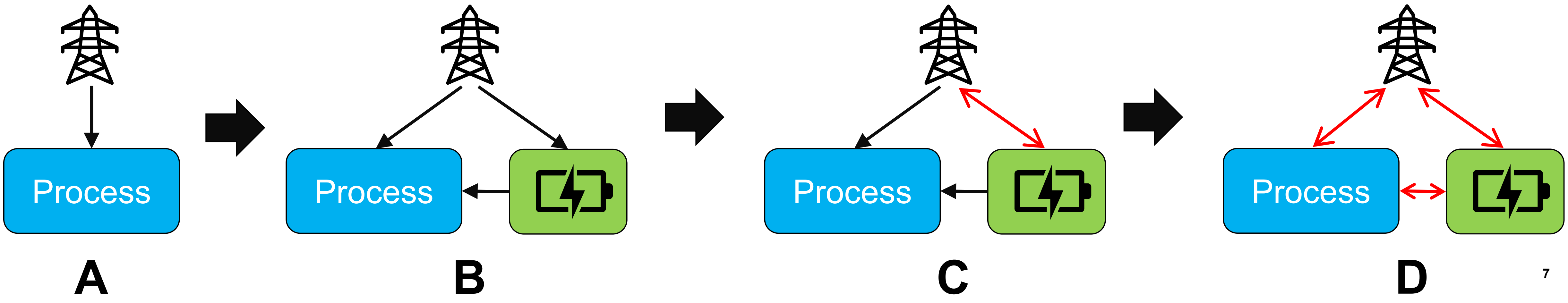
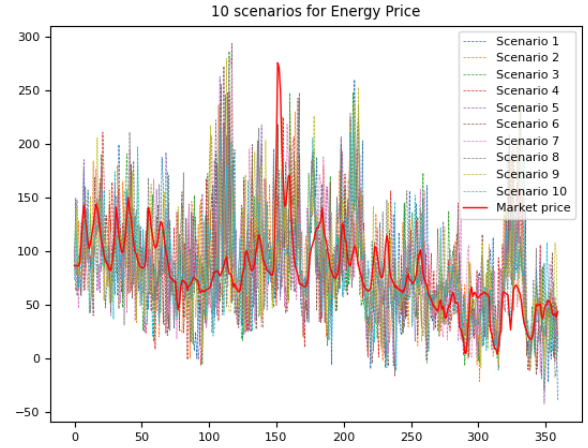
Future Coordination between Power Grid & Large Consumers

New ways of site-grid interaction to optimize use of renewables, stability of the grid and efficiency of the grid and sites. Many ways do this (A-D)

- Many products traded (energy, reserve) and electricity markets (yearly, hourly, spot)
- Goal: Secure sufficient mix of energy and capacity for resilient operation
- Additional option: Systematically embed P2X and X2P processes

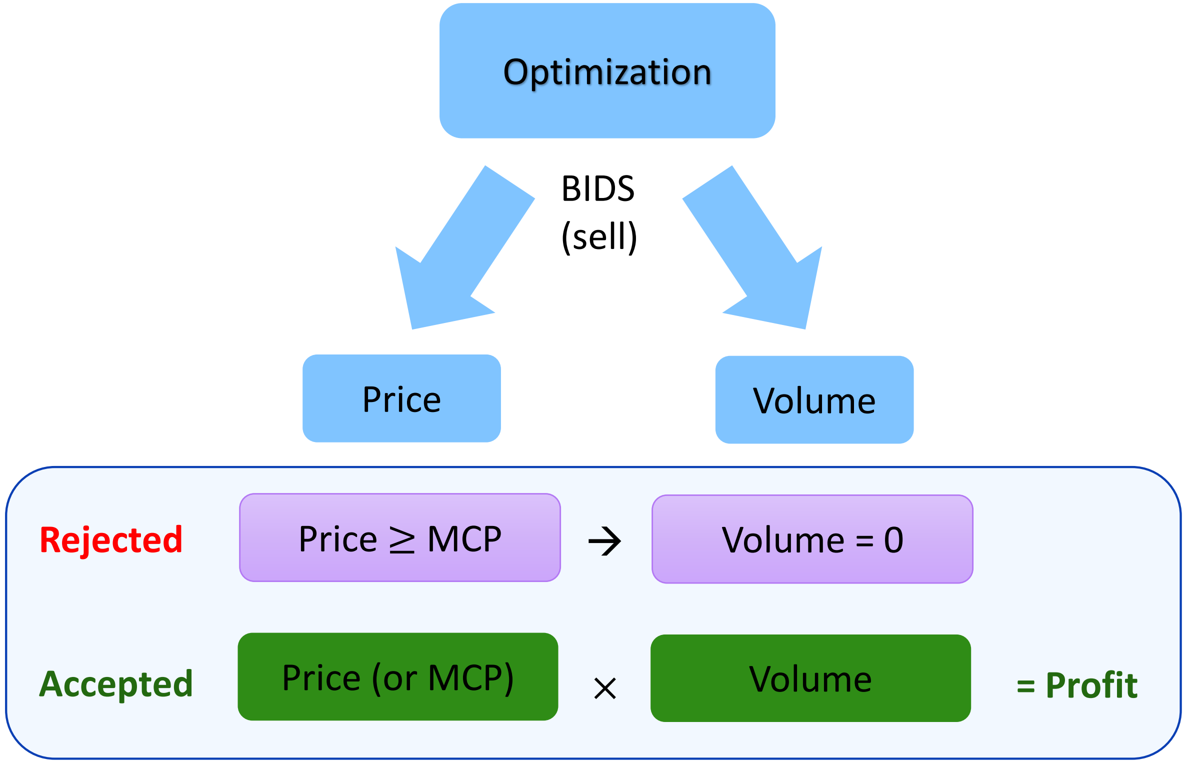


Bidding for Energy and Ancillary Services



Typically, one provides hourly (or more accurate) generation- and load forecasts (price/volume) 12-24 hours before operation

- Once the bidding process closes, accepted forecasts become commitments
- With increasing RES, more reserves are needed, i.e. capacity that might be called for (uncertainty)
- Capacities must be planned well in advance – coordinating planning and control



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What Is Flexibility in Processes?

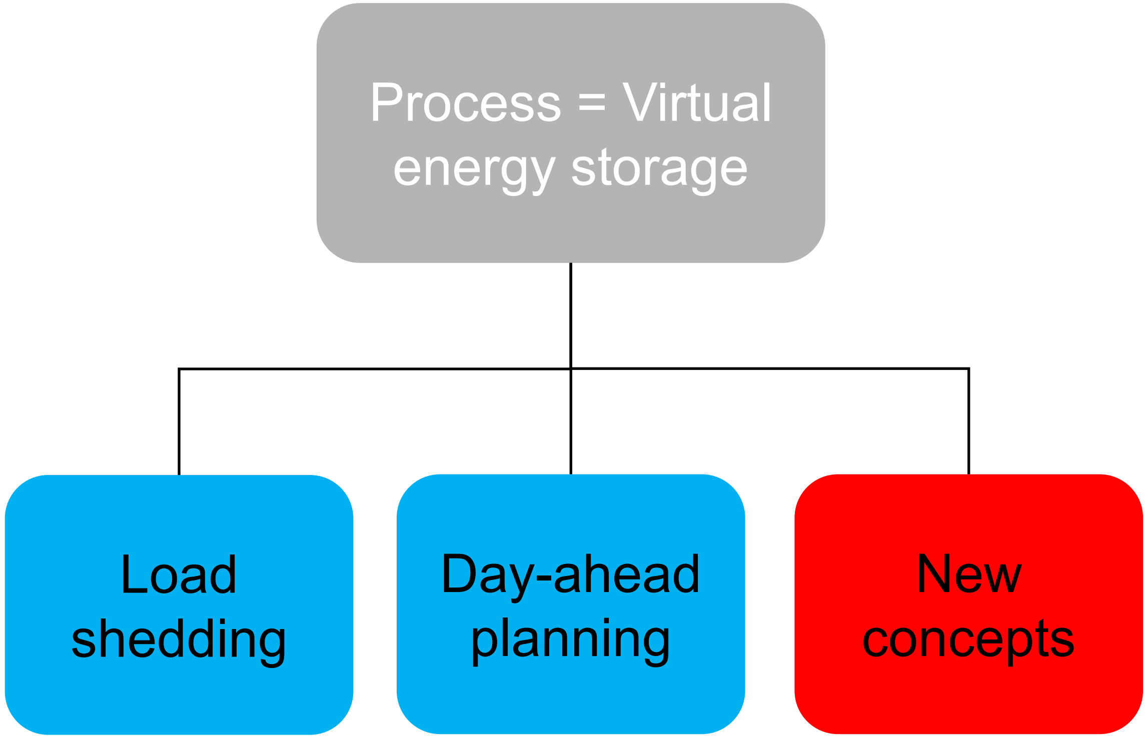
We need both shifting consumption and provision of reserves

Flexible electricity demand options

- Adjustable production rates
- Shiftable tasks
- Thermal/material buffers
- Inventory acting like storage

Outcomes: load shifting, peak shaving, ancillary flexibility

Often achievable without new hardware!



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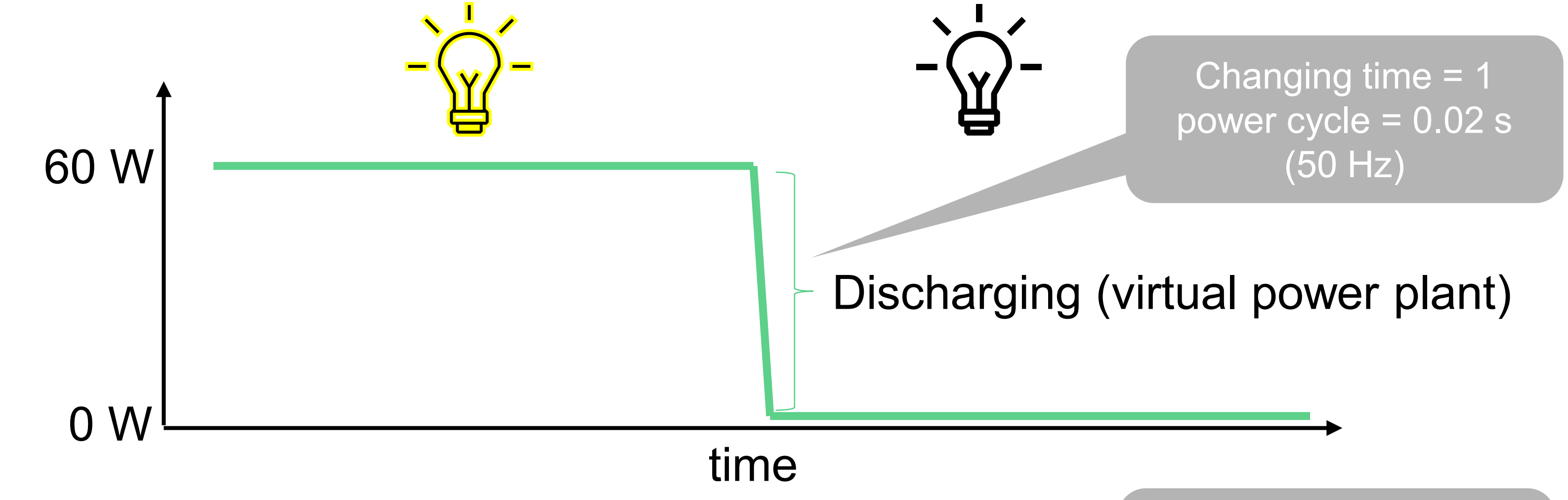
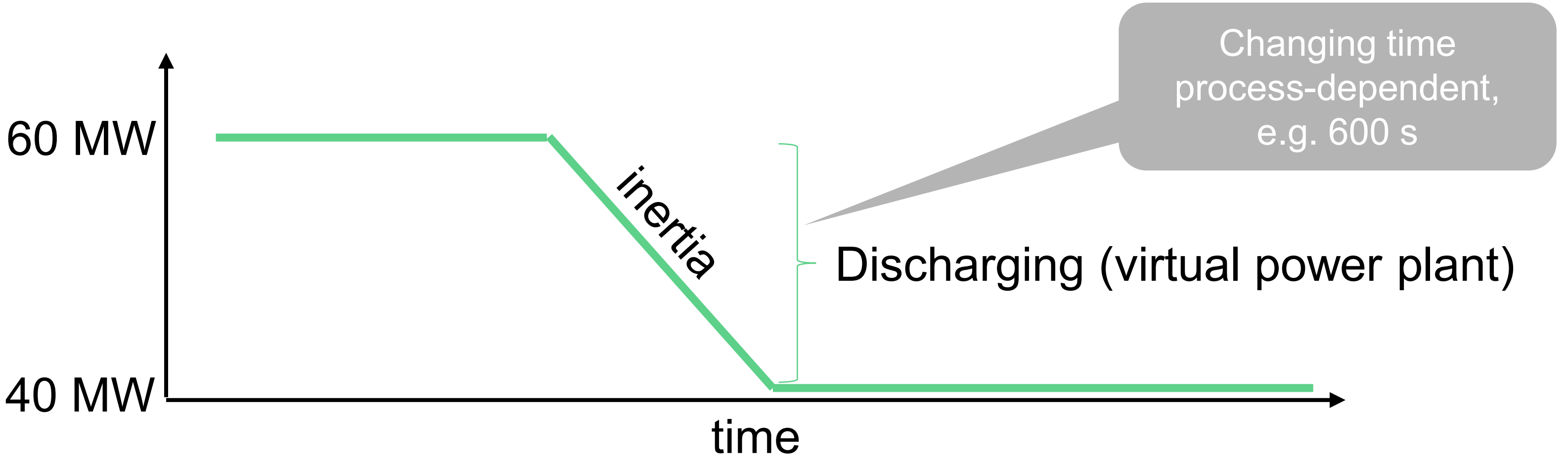
Changing Consumption Levels (Ramp Rates)

Examples with or without inertia





In the end the power level is not as interesting as the amount of energy that can be dispatched / stored within a given time interval!

Process-Grid Collaboration Creates Two-Sided Value

SITE (PROCESS) VALUE

- Lower exposure to price volatility
- Shift demand away from peaks
- Reduce demand charges
- Avoid infeasible schedules
- Capture flexibility revenues

SYSTEM (GRID) VALUE

- Provide balancing reserves
- Relieve network bottlenecks
- Absorb more variable renewables
- Improve resilience
- Defer selected grid upgrades

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A Flexibility Offer Must Be Measurable – and Safe

MAGNITUDE	RAMP RATE	DURATION	RECOVERY	RISK
How much demand can move	How fast demand can change	How long flexibility persists	Return to nominal operation	Quality and safety impact
≈ planning	≈ control	≈ both	≈ both	≈ control

QUALITY + SAFETY DEFINE THE ACTIVATION BOUNDARY

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The Integration Gap = Interface Problem

Shared objectives, constraints and information replace manual handoffs

Siloed operation		Co-designed system
local objectives		shared constraints
limited visibility	VS	actionable demand signals
manual coordination		feasible responses
unused flexibility		verified flexibility

Decomposition Coordinates without a Monolith

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Plant model

Production targets
Production constraints
Quality boundaries
Handle disturbances

G

Grid model

Minimum electricity costs
Network limits
Balancing needs
Maintain frequency

M

Market model

Prices and bids
Market commitments
Interface load/generation

Decomposition schemes require Coordination VARIABLES + Consistency CUTS

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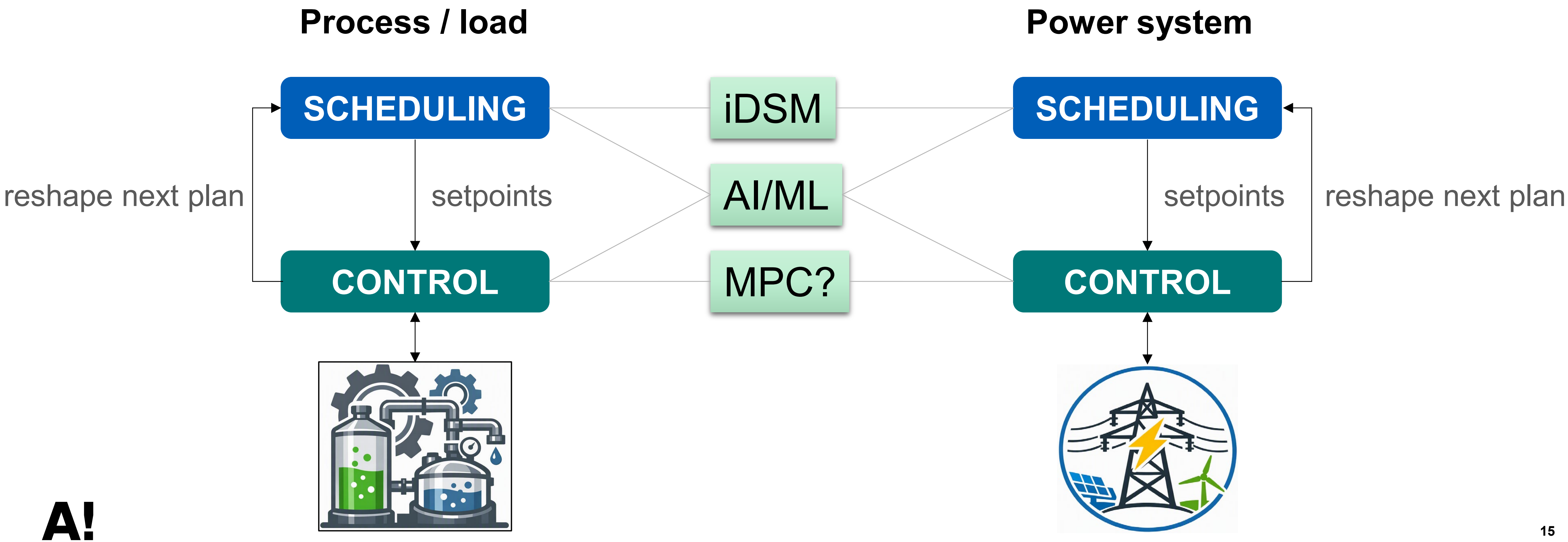
Scheduling and Control: Two Horizons of One Design



Markets Reward Flexibility Only When Execution Remains Feasible

Market commitments must remain feasible at execution time

- FORECASTS
- SCHEDULE
- CONTROL
- BIDDING

Storage changes the economics across time

Bids convert forecasts into commitments

Control must protect feasibility in real time

Value streams include load shifting, peak shaving and ancillary services

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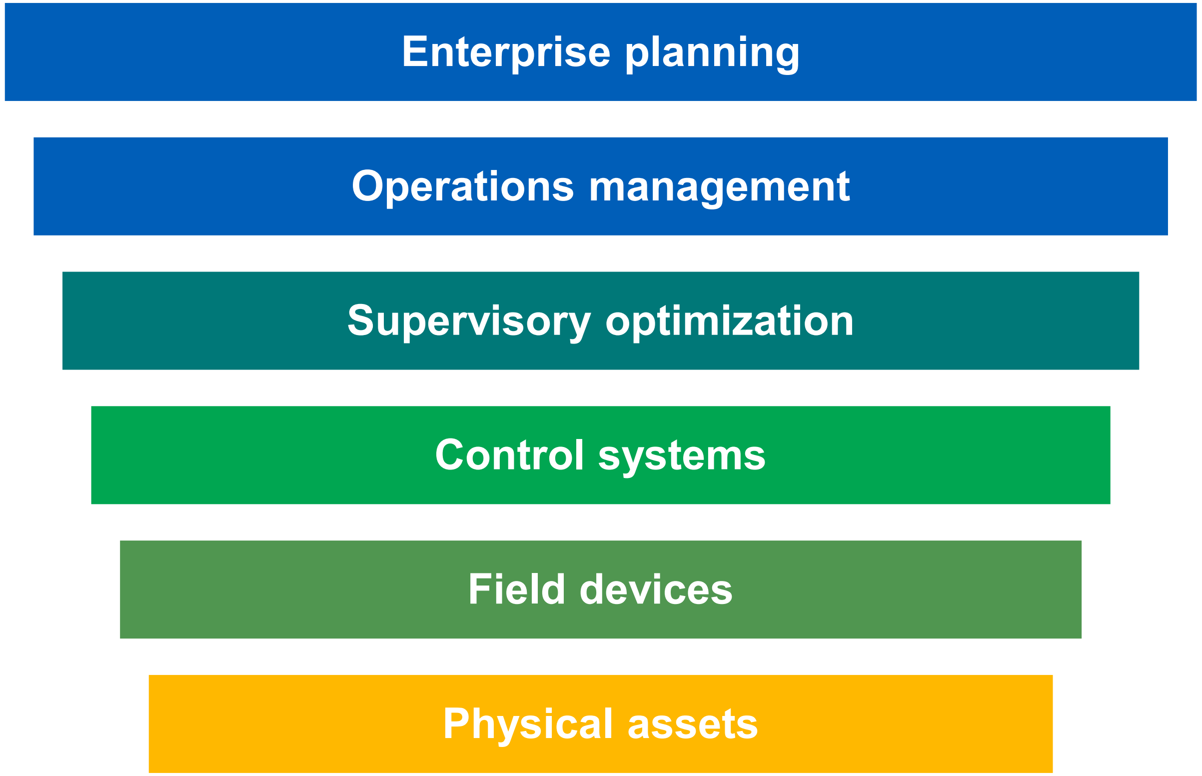
Integrate the automation pyramid selectively

Do not integrate everything. Integrate only where cross-layer constraints create value or risk

- Integrate where constraints are shared
- Keep fast safety loops local
- Define explicit data contracts
- Assign timing and responsibility
- Verify every cross-layer action



Open Problems from Co-Designed Energy Systems

New focus on demand-side management and better incentives to ensure that process industries and utilities operate in a truly collaborative manner

1. How to ensure sufficient energy supply to maintain stable production processes continuously in all situations?
2. How to create mechanisms to increase collaboration across various demand-side actors (even between competitors)?
3. How to redesign the electricity markets to provide stronger incentives for electricity users to support the stability of the power grid?
4. How to deal with more complex optimization problems due to stochasticity?
5. How to ensure efficient optimization of increased problem size due to 15-min trading intervals (or less)?

Kiitos
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